

A VERY DEEP IRAS SURVEY AT  $\ell_{II} = 97^\circ$ ,  $b_{II} = +30^\circ$ 

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**ABSTRACT.** A deep far-infrared (12-100 $\mu$ m) survey is presented using over one thousand scans made of a 4-6 deg<sup>2</sup> field at the north ecliptic pole by the Infra-red Astronomical Satellite (IRAS). Point sources from this survey are up to one hundred times fainter than the IRAS point source catalog at 12 and 25 $\mu$ m, and up to ten times fainter at 60 and 100 $\mu$ m. The 12 and 25 $\mu$ m maps are instrumental noise-limited, and the 60 and 100 $\mu$ m maps are confusion noise-limited. The majority of the 12 $\mu$ m point sources are stars within the Milky Way. The 25 $\mu$ m sources are composed almost equally of stars and galaxies. About 80 percent of the 60 $\mu$ m sources correspond to galaxies on Palomar Observatory Sky Survey (POSS) enlargements. The remaining 20 percent are probably galaxies below the POSS detection limit. The differential source counts are presented and compared with theoretical models. The 12 $\mu$ m source counts are found to be consistent with what is predicted by the Bahcall and Soneira Standard Galaxy Model (1980) using the B-V-12 $\mu$ m colors of stars without circumstellar dust shells given by Waters, Cote and Aumann (1986). The 60 $\mu$ m source counts are inconsistent with those predicted for a uniformly distributed, nonevolving universe. The implications are briefly discussed. A detailed description of the survey appears in Hacking and Houck (1986). A discussion of the scientific implications of the source counts and colors are discussed in Hacking, Condon, and Houck (1986).

## INTRODUCTION

There are two reasons for conducting an infrared survey to lower flux densities. The first is to detect trends in sources observed at higher flux densities. The changes might be detected in the shape of the luminosity function (i.e., changes in relative distribution of sources vs. luminosity) or the position of the luminosity function in the density -- luminosity plane (e.g., changes in the space density of sources or luminosity evolution at cosmological redshifts). The second is to search for new classes or types of objects. An obvious example would be the detection of a nearby, isolated brown dwarf. It is also possible that a new type of source, as yet unthought of, might be detected.

## THE DATA

The survey is located at the north ecliptic pole, in the constellation of Draco, at  $18^h$ ,  $+66^\circ$ ;  $\ell_{II} = 97^\circ$ ,  $b_{II} = 30^\circ$ , and covers 4.3 square degrees at 12 and 25 $\mu$ m and 6.3 square degrees at 60 and 100 $\mu$ m.

There are two types of data used in the survey: 488 scans from the IRAS all-sky survey and 141 pointed observations. The survey scans cover the entire

field approximately uniformly. Each survey scan map is  $1/2^\circ \times$  up to  $4^\circ$  and consists of data from a single scan of the satellite across a portion of the field. The pointed observations are centered on NGC 6543, which is located very near the ecliptic pole and was used as a calibrator for the IRAS mission. Each pointed observation consists of three to six scans made at half the IRAS survey scan rate and results in a map of dimensions  $1/2^\circ \times 1$  to  $1.75^\circ$ . Since NGC 6543 was the target of the pointed observations, only the central three square degrees is covered by them, and the coverage is nonuniform, with the region around NGC 6543 (near the center of the field) observed the most. Over one thousand scans were combined to form the final maps, making this the deepest infrared survey to date. At 12 and  $25\mu\text{m}$  it is likely to remain so until the next generation infrared satellite can be flown (e.g., SIRTf or ISO). At 60 and  $100\mu\text{m}$ , it may prove possible to probe slightly deeper in the field (and a few other smaller select fields) using different filtering techniques. Point sources as faint as 5-10 mJy are in the 12 and  $25\mu\text{m}$  maps with  $\text{SNR} > 3-5$  (a factor of 50 to 100 times fainter than the IRAS point source catalog), 50 mJy at  $60\mu\text{m}$  (ten times fainter than the IRAS PSC), and 100-200 mJy at  $100\mu\text{m}$  (five to ten times fainter than the IRAS PSC).

Two images of each survey scan and each pointed observation were made: 1) A full-intensity image was made that approximates the true appearance of the infrared sky; 2) a point-source filtered image was made that improves the signal-to-noise ratio of point sources. Several preliminary maps were made from subsets of the data to check for moving or spurious sources. All of the images were then summed to form final intensity and point source filtered images.

The intensity maps indicate that there is a great deal of extended emission in the field at 60 and  $100\mu\text{m}$ . The  $60\mu\text{m}$  point source filtered map contains very little extended emission. The  $100\mu\text{m}$  point source filtered map is contaminated with extended emission, however. This is due to the larger angular size of the  $100\mu\text{m}$  point spread function that is similar in size to much of the structure present in the extended emission. For this reason,  $100\mu\text{m}$  fluxes are quoted only for sources also detected at  $60\mu\text{m}$ , where contamination from the extended emission is less likely.

## RESULTS

The point source density in this field at 12 and  $25\mu\text{m}$  is quite low compared to the effective beam size (10-15 sources per square degree brighter than 20 mJy), so that the 12 and  $25\mu\text{m}$  surveys are limited by instrumental noise.

At  $60\mu\text{m}$ , the effective beam size and the source density (20 sources per square degree brighter than 50 mJy) are larger, resulting in a confusion noise-limited survey ( $\sigma_{\text{conf}} = 20$  mJy). Extended emission and confusion prevented an unbiased  $100\mu\text{m}$  survey.

No moving or spurious (single event) sources were found in any of the preliminary maps.

The point source filtered maps were used to extract the point source sample. The point sources were compared with the Smithsonian Astrophysical

Observatory Star Catalog (1966) and the Palomar Observatory Sky Survey (POSS) plates. A summary of the comparison is presented in Table 1.

TABLE 1 - Summary of Point Sources from Deep Survey

$\lambda$	Total Number <sup>a</sup>	Stars %	Galaxies %	Unidentified %
12 $\mu$ m	46	89	11	0
25 $\mu$ m	36	50	47	3 <sup>b</sup>
60 $\mu$ m	99	0	~80	~20 <sup>c</sup>

<sup>a</sup> Excluding NGC 6543

<sup>b</sup> Probably a distant Seyfert galaxy

<sup>c</sup> Probably galaxies below POSS detection limit

The distribution of sources vs. flux density was modeled, assuming a power law of the form:

$$n_{>F_v} = A F_v^{-\alpha}$$

where  $n_{>F_v}$  is the number of sources with flux density greater than  $F_v$  per square degree;  $A$  and  $\alpha$  are constants. Values of  $\alpha$  of  $0.76 \pm 0.11$  and  $1.79 \pm 0.17$  were found for the 12 $\mu$ m (mostly stars) and 60 $\mu$ m (extragalactic sources) point source samples, using the method of maximum likelihood. The Kolmogorov test revealed that the power law distribution assumed for the source counts is consistent with the data at 12 and 60 $\mu$ m. Since the 25 $\mu$ m sample is composed of both stars and galaxies, the 25 $\mu$ m distribution is a linear combination of the 12 and 60 $\mu$ m distributions.

## DISCUSSION

The 12 $\mu$ m source counts are consistent with star counts predicted by the Bahcall and Soneira Standard Galaxy Model\*, using the B-V-12 $\mu$ m colors given by Waters, Cote, and Aumann (1986) for stars without circumstellar dust shells. In particular, the total number (33) and the value of  $\alpha_{12\mu}$  (0.78) is successfully predicted (see Hacking, Condon, and Houck 1986 for details). Figure 1 shows differential star counts extrapolated to very low flux densities at the north galactic pole (not covered in this survey) as predicted by the model. The 12 $\mu$ m counts above ~10 Jy are dominated by stars with circumstellar dust shells (Hacking, et al. 1985), which are not included in Figure 1. The expected galaxy counts at 12 $\mu$ m are also plotted in Figure 1. As can be seen, galaxies should dominate the 12 $\mu$ m point source counts below ~10 mJy at the galactic poles.

The 60 $\mu$ m source counts were modeled in a similar fashion to the radio

\*See Hacking, Condon, and Houck (1986) for a description of what was used, and Bahcall and Soneira (1980), for a detailed description of the model.

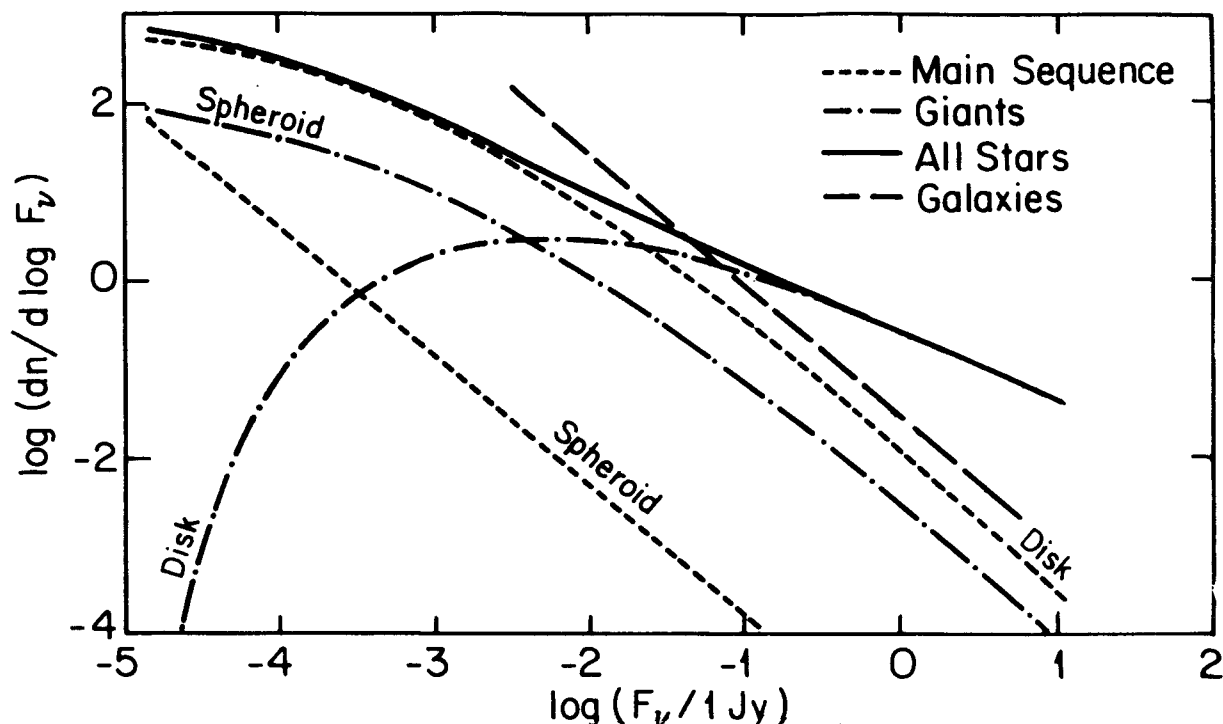


Figure 1 - Predicted  $12\mu\text{m}$  differential star counts at the north galactic pole using the Bahcall and Soneira Standard Galaxy Model (1980) and B-V- $12\mu\text{m}$  star colors from Waters, Cote, and Aumann (1986). The log of the number of sources per square degree, per decade of flux density is plotted versus log flux density (in Janskys). The differential counts for all stars are given by the solid line. In addition, the differential counts for main sequence and giant stars are each shown for the disk and spheroidal components. The expected galaxy counts at  $12\mu\text{m}$  are also shown.

source counts using the model of Condon (1984) with and without evolution, using the  $60\mu\text{m}$  luminosity function and color-luminosity data given by Soifer, et al. (1986). The predicted counts for an evolutionary model and a nonevolving model are compared with the observed counts in Figure 2. Although the source counts favor the evolving model, they do not constrain the type of evolution that may have been detected. In addition, evolution is not the only explanation for the discrepancy between the observed source counts and the source counts predicted for a nonevolving universe. In particular, a galaxy cluster in the direction of this survey with a redshift of  $\sim 0.2$  could produce this effect. Clearly, redshift data are needed to resolve the nature of this discrepancy.

#### ACKNOWLEDGEMENTS

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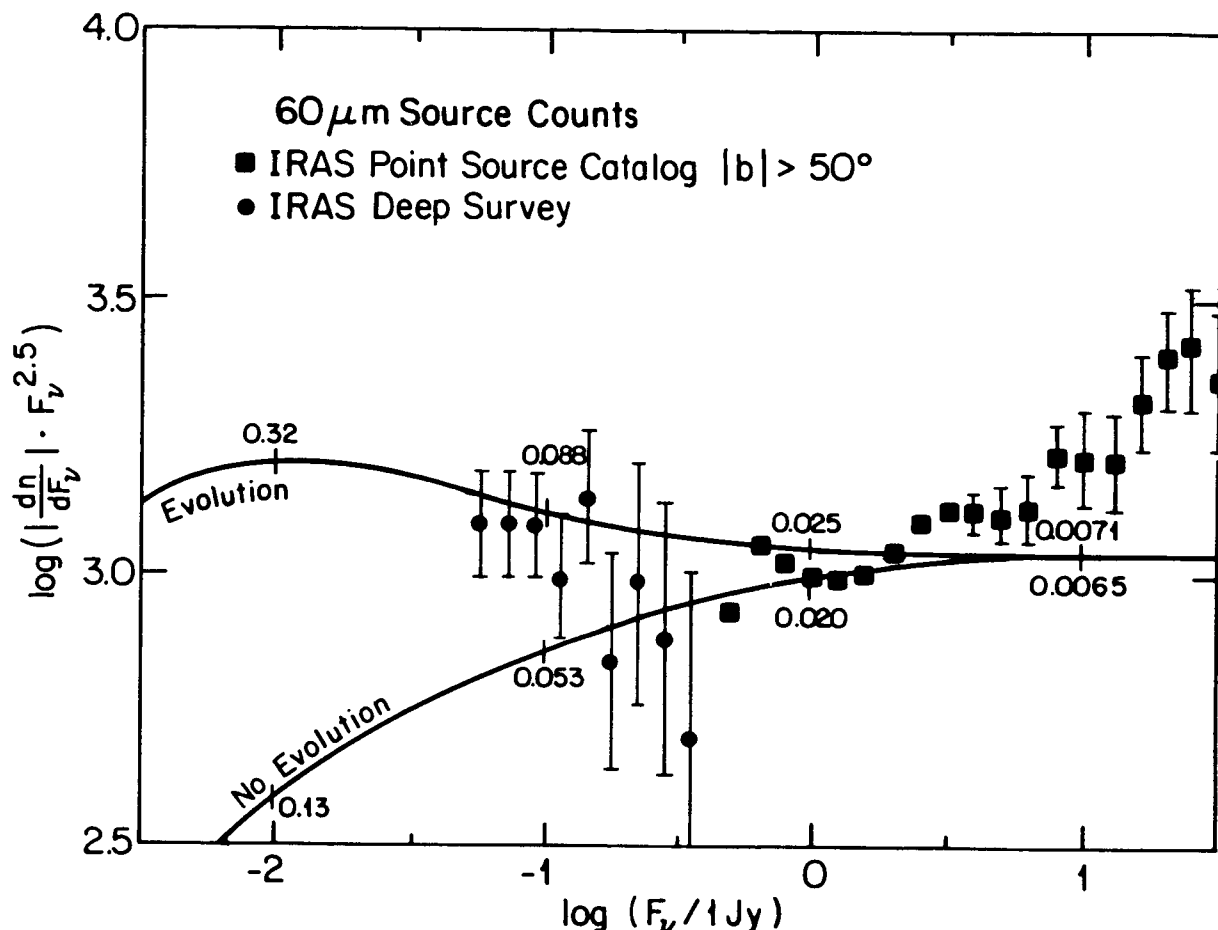


Figure 2 - Predicted  $60\mu\text{m}$  differential galaxy counts with and without evolution, using the luminosity function and luminosity-color data from Soifer et al. (1986). Tick marks indicate median redshifts of the differential counts. The data from the deep survey are plotted as filled circles, and the data from the IRAS Point Source Catalog with  $|b| > 50^\circ$  are plotted as filled squares. Much of the increase in the source counts above 10 Jy is due to the Virgo cluster. The luminosity function has been shifted down by 15% so that the non-evolutionary model agrees with the differential counts at 1 Jy. See Hacking, Condon, and Houck (1986) for details.

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## DISCUSSION

WYNN-WILLIAMS:

Are there other IRAS fields that can be analyzed to this depth, or have we hit the limit of what is possible with IRAS?

HACKING:

This is probably as deep as we can go at 12 and  $25\mu\text{m}$ . There are smaller deep fields that are almost as deep as this field at 60 and  $100\mu\text{m}$ . In addition, it may prove possible to reduce the confusion noise in this field using different filtering techniques, allowing a study up to a factor of 2 fainter in this field.

WEEDMAN:

Your counts at  $60\mu\text{m}$  agree precisely with expectations from the average luminosity function now available. The very close agreement must be fortuitous, but it is pleasing that all of the data are coming together so consistently.